SOLUTION TO.

EP155.

FEB, 2004

MIDTERM.

EP155 February 9, 2004 Midterm

Name: ____________________ Student No. ____________________

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Date: February 9, 2004
Time: 1 hours
Restrictions: Calculators and one 8.5 by 11 sheet of paper only.
              The sheet of paper can be written on both sides.
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Put a box around all your answers!

CONSTANTS:

- $k = 9.0 \times 10^9$ N $\cdot$ m^2/C^2
- Inferred absolute zero temperature for copper, $T_o = -234.5$ degrees Celsius
- resistivity of copper at 20 degrees Celsius is $\rho_{20} = 1.723 \times 10^{-6}$ Ωcm
- temperature coefficient of resistance for copper is $\alpha_{20} = 0.00393$/degree Celsius
- Field strength that breaks down air is 30 kV/cm

PREFIXES:

- μ is 10^{-6}
- m is 10^{-3}
- k is 10^3

QUES.	MARKS
Q1	______________
Q2	______________
Q3/Q4	______________
Q5	______________
Total	______________

1. The map of an electric field is shown in Figure 1. Note, there are several points that are clearly labeled and one force vector shown on the map. The lines on the map indicate constant energy levels, where the levels are in units of J/C. The lines are drawn for energy level increments of 0.500 J/C, i.e. 0.500 V.

   It is known that it takes work to move positive charge from left to right anywhere on the map. It is also known that the force exerted by the electric field on ± 0.100 mC (sign of the charge is not given so could be positive or negative charge) of charge located at point D is 1.00 N in the direction shown on the map.

(2) (a) What is V_{HA}?

(1) (b) i. What is the sign of the charge located at point D?

(2) ii. What is the strength of the electric field at point D?

(2) (c) Approximately what is the magnitude of the force on a point charge of 1 μC located at point G?

(2) (d) Draw an electric field line through point B. Draw a long line that spans the map and not just a short segment of the line near point B. Be sure to put an arrow on the field line to show the direction of the field.

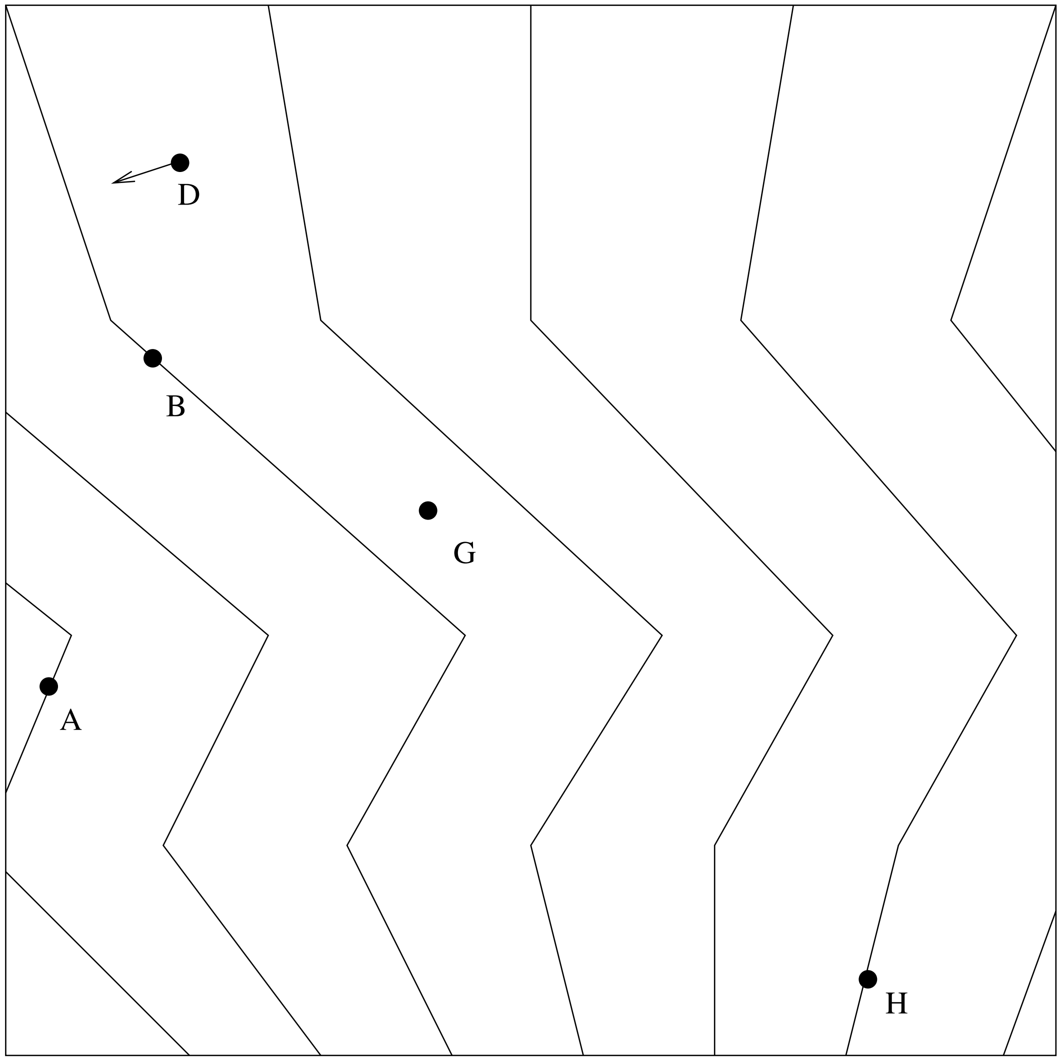


Figure 1: Electric field map with only constant energy contours which are 0.5 V apart

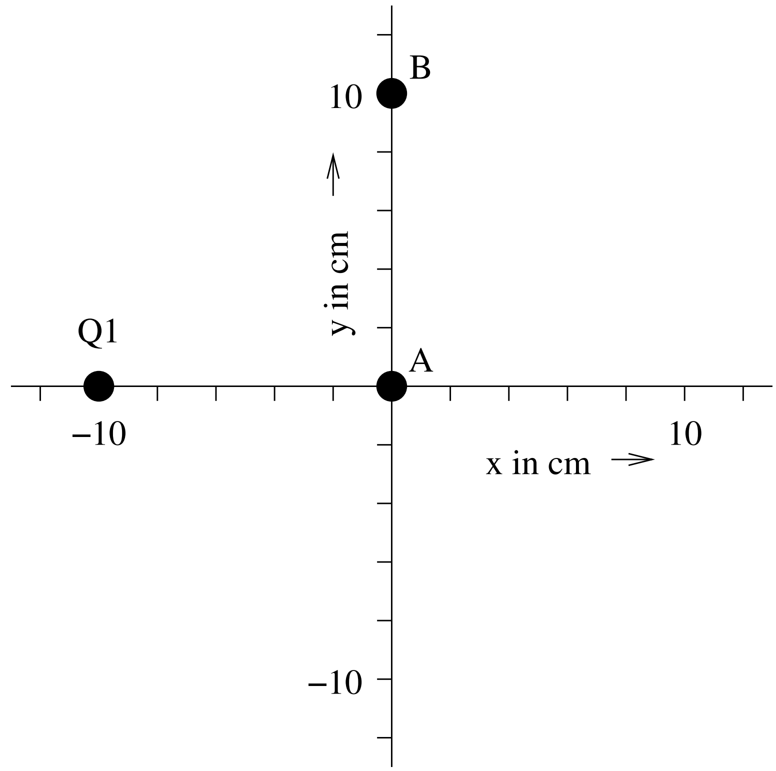


Figure 2: Diagram showing position of charged particle Q1.

2. A point charge of +1.00 mC, referred to as Q1, is located in a plane at x=-10 cm and y= 0.00 cm as shown in Figure 2. Two other points are labeled in Figure 2. Point A is at the origin and point B is at x = 0.00, y = 10 cm.

(3) (a) How much work is required to move test charge Qt = +2 μC from point A to point B?

(2) (b) What is V_{BA}?

(3) (c) The field is changed by adding a second point charge of Q2 = +3.00 mC at x = 10 cm, y = 10 cm, as shown in Figure 3. What is V_{BA}?

(d) A ring of copper wire is placed around point charge Q1 in Figure 2 as shown in Figure 4.

(2) i. Will the presence of the wire ring change the electric field? If so, what happens to make the electric field change?

(2) ii. Will the wire experience a net force due to Q1? If so, in what direction?

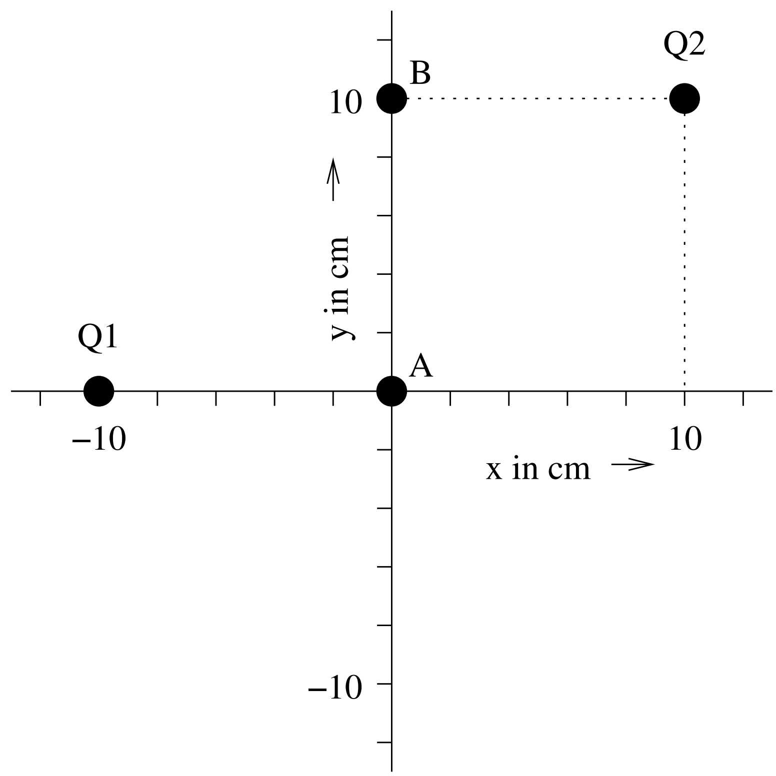


Figure 3: Diagram showing position of two charged particles, Q1 and Q2.

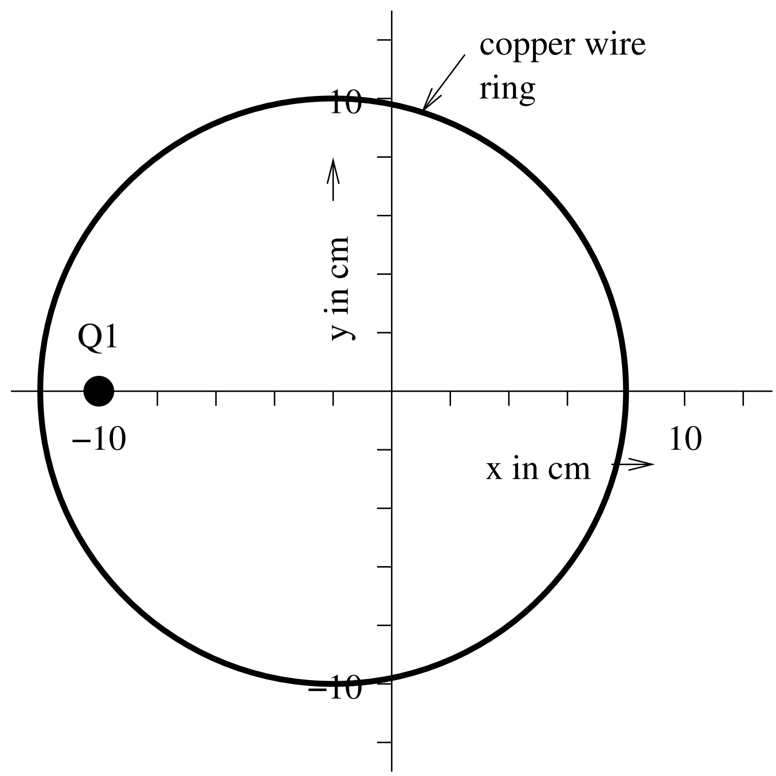


Figure 4: Diagram showing position of a copper wire around charged particle Q1.

3. A copper wire of unknown length has a cross sectional area of 1.0×10^{-7} m^2 and a resistance of 10.0 kΩ at a temperature of 20 degrees Celsius.

(3) (a) What is the length of the wire?

(3) (b) This wire is taken to another location so that it is no longer at a temperature of 20 degrees Celsius. The resistance is measured to be 10.8 kΩ. What is the temperature at the other location?

(2) 4. A spark plug has a gap of 0.7 mm, i.e. the two terminals of the spark plug are 0.7 mm apart. To force a spark a voltage is applied across the two terminals. This voltage increases with time until a spark occurs. Approximately what is the voltage across the terminals of the spark plug when the spark starts to occur?

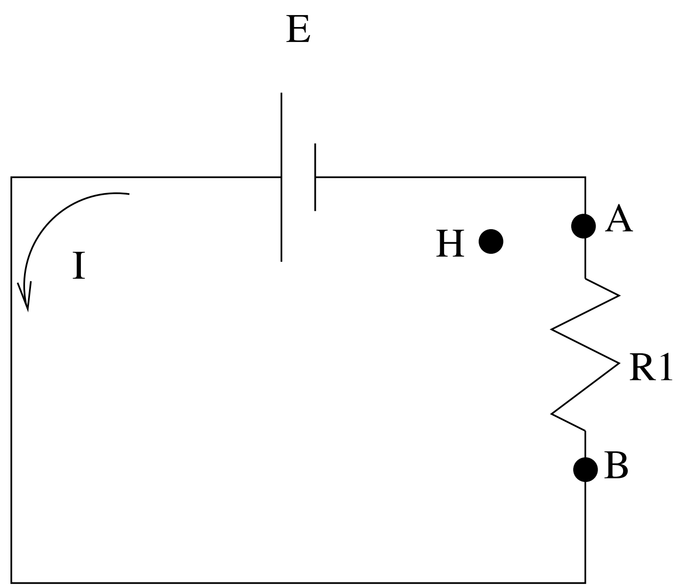


Figure 5: Circuit Diagram

5. Consider the circuit shown in Figure 5. The current flowing in this circuit is 25.0 mA in the counter-clockwise direction. Resistor R1 has value 4000 Ω. The voltage of the battery is not given.

(2) (a) What is the voltage at point A with respect to point B?

(1) (b) What is the battery voltage, i.e. what is E?

(2) (c) Is there an electric field present in R1? If so, what is its direction?

(2) (d) How much work would it take to move -0.100 C of charge clockwise from point B, through the battery to point A?

(2) (e) How much negative charge does the battery move from its positive terminal to its negative terminal in 1 hour?

(2) (f) How much electrical energy does R1 convert to heat in a 35 s interval?

(2) (g) Is there an electric field at point H?
If so, draw the approximate direction of the field on the circuit diagram.

1. a) $V_{HA} = \frac{W}{Q}$ where W is the work required to move charge Q from point A. to point H.

It is given in the question that it takes work to move positive charge from left to right. Since point H is to the right of point A. W will be positive if Q is positive ∴ V_{HA} is positive

$$|V_{HA}| = (5\ \cancel{\text{contours}})\left(\frac{.5V}{\cancel{\text{contour}}}\right) = \boxed{2.5V}$$

1 b) i) It takes work to move positive charge to the right. The electric field will excert a force in the opposited direction. Since the force vector is pointing leftward, the charge at point D is positive

$\boxed{\text{positive charge.}}$

ii) $E = \frac{F}{Q}$ where F is the force exerted by the electric field on charge Q.

$$\therefore \boxed{E = \frac{1.00N}{0.100mC} = 10.0\ k\frac{N}{C} \text{ or } 10.0\ \frac{KV}{m}}$$

1c) Let E_D be the electric field strength at point D and E_G be the electric field strength at point G. Then

$$E_D = \frac{\Delta V}{\Delta X_D} \quad ; \quad E_G = \frac{\Delta V}{\Delta X_G}$$

where $\Delta V = 0.5\,V$ and ΔX_D and ΔX_G. are the distances between contours. Then

$$\frac{E_G}{E_D} = \frac{\left(\frac{\Delta V}{\Delta X_G}\right)}{\left(\frac{\Delta V}{\Delta X_D}\right)} = \frac{\Delta X_D}{\Delta X_G}$$

$$E_G = E_D \frac{\Delta X_D}{\Delta X_G}.$$

from measuring distance on the graph $\frac{\Delta X_D}{\Delta X_G} \simeq 1.6$

$\therefore\ E_G \simeq 1.6\, E_D$

$\therefore\ F \simeq E_G Q = (1.6)(E_D)\, 1 \times 10^{-6}\, C$

$F \simeq 1.6\,(10.0 \times 10^{3}\, \frac{N}{C})(1 \times 10^{-6}\, C)$

$\boxed{F \simeq 16.0\ mN}$

1c) The scale on the map is not given and is not needed to do this question. However, it was not stated that the map was not drawn to scale. Therefore, solutions based on the map being drawn to scale are accepted. Such a solution follows:

$$F_{QG} \simeq F_{Ave} = E_{Ave} Q_t = \frac{\Delta V}{\Delta X} Q_t$$

where ΔV is the change in potential between neighbouring contour lines i.e. $\Delta V = 0.5\,V$ and, Δx is the distance between the neighbouring contours measured along the electric field line that runs through point G. $\Delta X \simeq 1.8\,cm$

$$F_{QG} \simeq \left(\frac{0.5V}{1.8\,cm}\right) 1\mu C = \frac{0.5\,V}{0.018\,m} 10^{-6} C$$

$$F_{QG} \simeq 27.8 \times 10^{-6} \frac{V}{m} C = 27.8 \times 10^{-6} \frac{J}{\cancel{C} m} \cancel{C}$$

$$\boxed{F_{QG} \simeq 27.8 \times 10^{-6} N}$$

1d)

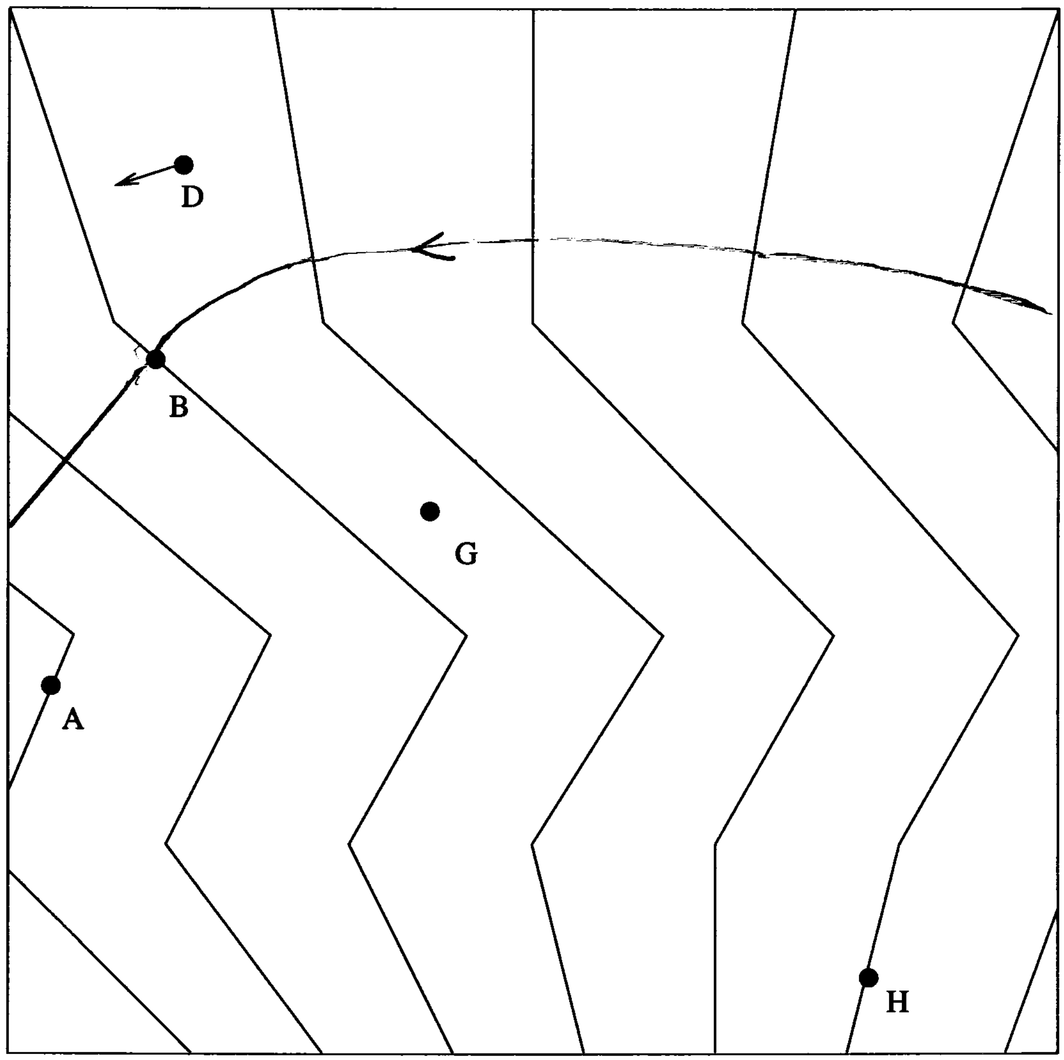
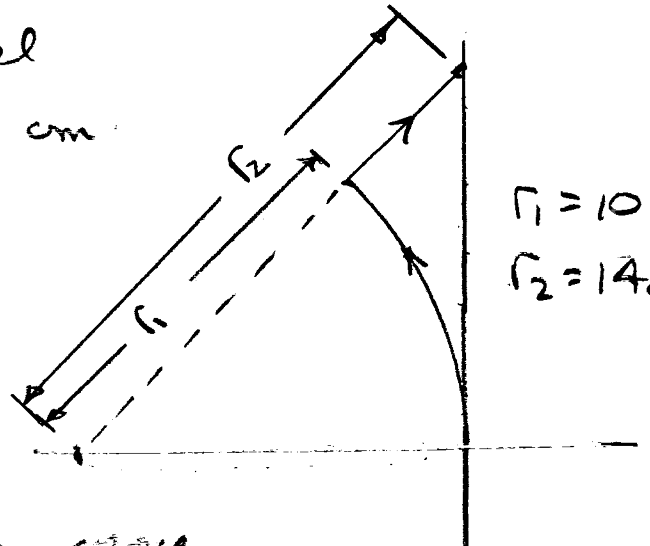


Figure 1: Electric field map with only constant energy contours which are 0.5 V apart

2. a) Move the charge as shown below.
Along the energy level contours of radius 10 cm from Q_1 and then along a field line to point B.



The work required to move charge Q_t along a field line due to charge Q_1 is

$$|W| = \left| k Q_1 Q_t \left[\frac{1}{r_1} - \frac{1}{r_2} \right] \right| \; ; \text{ where } r_1 = 10\text{ cm}, \; r_2 = 14.1\text{ cm}.$$

$$|W| = 9.0 \times 10^9 \frac{N m^2}{C^2} (1.00\, mC)(2\, \mu C) \left[\frac{1}{10\,cm} - \frac{1}{14.1\,cm} \right]$$

$$|W| = 527\,J$$

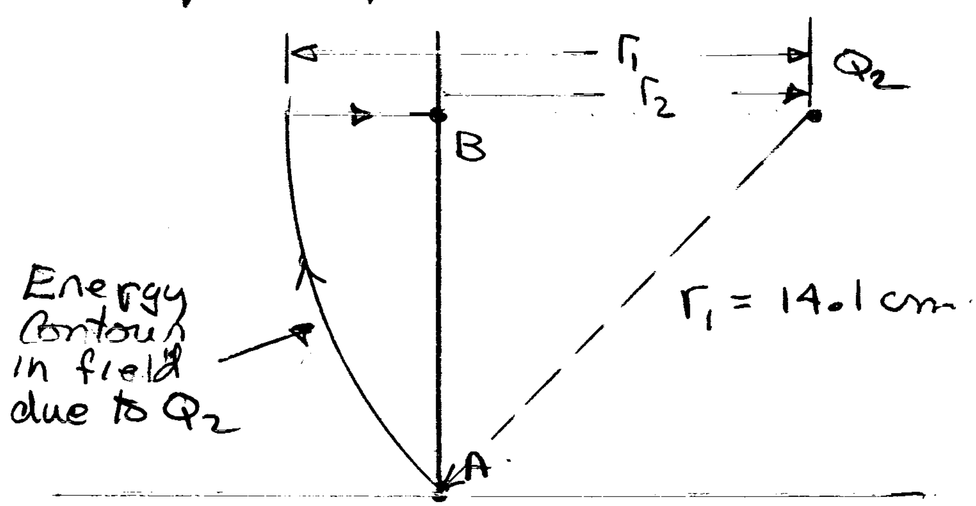
Since both Q_1 and Q_t are positive the electric force is one of repulsion so the field is doing the work. Therefore it will take negative work to move the charge.

$$\boxed{W = -52.7\,J}$$

b) $V_{BA} = \frac{W}{Q_t} = \frac{-52.7\,J}{2\mu C} = -2.63 \times 10^{7} \frac{J}{C}$

$$\boxed{V_{BA} = -2.63 \times 10^{7}\,V}$$

c) Find work required to move test charge Q_t against force due to Q_2.



$|W_2| = \left| K Q_2 Q_t \left[\frac{1}{r_1} - \frac{1}{r_2} \right] \right|$; $Q_t = 1\mu C$

In this case work done is positive

$W_2 = +158.2$

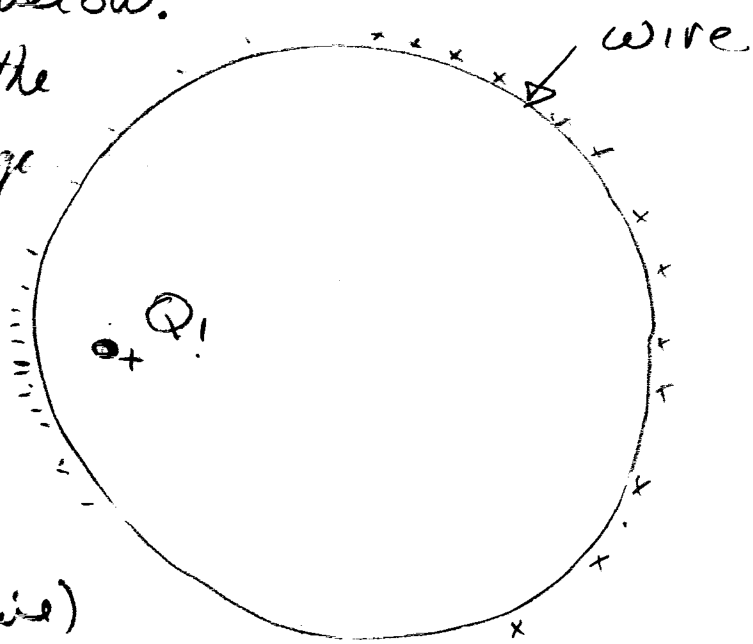
Total work required when both Q_1 and Q_2 are present is $W = -52.7 + 158.2 = 105.5$

$$\boxed{\therefore V_{BA} = +\frac{105.5\,J}{2\mu C} = +5.27 \times 10^{7}\,V}$$

d) i) Yes the presence of the wire will change the electric field. This is because negative charge will move in the wire under the force of attraction to Q1. The field did the work to move the charge therefore the field will be weaker.

ii) Yes there will be a net force on the wire. The excess charge in the wire will be distributed as shown below.

The force on the negative charge is to the right (attractive) and the force on the positive charge is to the right (repulsive)



∴ the force will be in the +x direction

$\boxed{\text{Yes wire experiences force in +x direction i.e. } \rightarrow}$

3. a) $R = \rho \dfrac{l}{A}$ where R is resistance.
ρ is resistivity
l is length
A is cross sectional area

$$\therefore \; l = \frac{RA}{\rho} = \frac{10.0 \times 10^{3}\,\Omega \;\; 1.0 \times 10^{-7}\,m^2}{1.723 \times 10^{-6}\,\Omega\,cm.}$$

$$\boxed{l = 5.80 \times 10^{4}\ m}$$

b) We know.

$$R_2 = R_1 \left(\frac{T_2 - T_0}{T_1 - T_0} \right)$$

$$\therefore \; T_2 = \frac{R_2}{R_1}(T_1 - T_0) + T_0$$

$T_0 = -234.5°C$
$T_1 = 20°C$, $R_1 = 10.0\,k\Omega$
$R_2 = 10.8\,k\Omega$

$$\therefore \; T_2 = \left(\frac{10.8}{10.0}\right)\left(20°C - (-234.5°C)\right) - 234.5°C$$

$$\boxed{T_2 = 40.4°C}$$

4) The electric field strength across the gap is

$$E \simeq \frac{V_{gap}}{\Delta x} = \frac{V_{gap}}{0.7\,mm}$$

A spark will occur when the field is strong enough to break down air

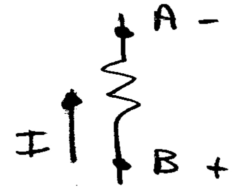
i.e. $E = 30\frac{kV}{cm}$ for this to happen.

$$\frac{V_{gap}}{0.7\,mm} = E = 30\frac{kV}{cm}$$

$$\therefore V_{gap} = \left(30\frac{kV}{cm}\right)(0.7\,mm)$$

$$\boxed{V_{gap} = 2.1\ kV}$$

5 a) The current flows through the resistor from point B to point A. Therefore the direction of the electric field is from B to A. Therefore the field does the work in moving + charge from B to A



$I = 25 ma.$

$\therefore V_{AB}$ is negative.

Ohm's law

$$V_{BA} = IR = (25.ma)(4000\Omega)$$

$$= 100V$$

$$\boxed{\therefore V_{AB} = -100V}$$

b) $\boxed{E = V_{BA} = 100V}$

c) Yes - in the direction the current is flowing which is upward.

d) $\boxed{W = V_{AB}\,Q = (-100V)(-0.100C) = 10J}$

e) $Q = I\Delta t = (25mA)(1\ \text{hour})$

$$\boxed{Q = (0.025A)(3600s) = 90C}$$

5f) $W = P\Delta t$; $\Delta t = 35s$.

$P = I^2 R = (0.025A)^2 (4000\Omega)$

$\therefore W = (0.025A)^2 (4000\Omega) 35s$.

$\boxed{W = 87.5\,J}$

5g) yes. The wire connected to the negative terminal of the battery will be negatively charged. The wire connected to the positive terminal will be positively charged. Therefore + charge located at point H will be attracted to the wire connected to the negative terminal and away from the wire connected to the positive terminal. The direction will be upward - similar to the direction of the field in **R1**.

$\boxed{\text{yes - upward}}$